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The evolution and effectiveness of Maintenance Resource Management (MRM)✩

James C. Taylor*

School of Engineering, Human Factors, Santa Clara University, 500 EL Camino Real, Santa Clara, CA 95053-0590, USA

Abstract

Maintenance resource management (MRM) is defined as collaboration and communication for maintenance safety. Its origins and separate roots are identified. Two recent and well-documented case examples are reviewed and assessed in terms of degree of top management support, the quality of intervention, and the extent of measurement and feedback. Systems thinking and culture change as current themes in aviation human factors are discussed and accumulating evidence is examined. The view of maintenance unity in the context of the larger organizational system is proposed.

Relevance to industry

Maintenance human factors plays an increasing part in airline safety. Maintenance resource management is the part of maintenance human factors which addresses the issues of management, organization, communication, problem solving, and decision making. MRM is important in addressing error correction and avoidance in the stressful and complex environment of commercial aviation. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Since the late 1980s the application of social and organizational psychology, work sociology, and anthropology in aviation maintenance have increased dramatically. Collectively called maintenance resource management, or MRM, this application of behavioral and social sciences has been gaining momentum. This interest in behavioral sciences parallels the growing presence of the more traditional individual aviation human factors topics (individual selection and training, equipment design, paper forms design and language use, human physiology, and workplace safety and health) in aviation maintenance and engineering operations.

Like any new development, MRM has suffered problems of definition. What MRM has become is a matter of who is doing it. The world of commercial aviation is practical if it is nothing else. Aviation maintenance executives and union leaders are no fools – there is little reason for them or others in maintenance to think twice about something as

* Tel.: + 1-408-554-4154; fax: + 1-408-554-5474.

E-mail address: jctaylor@scu.edu (J.C. Taylor).

academic as social science. It is obvious from this that a "theory of MRM" did not come first – and its observers are only now struggling to identify a "construct" (see Bradley, 1995; Lofaro, 1996).

1.1. A definition of MRM

Taken together, two recent innovations in maintenance define MRM. These innovations are (1) labor-management cooperation for improving safety and (2) the development of positive and assertive communication practices. MRM, by this definition, is not addressing individual human factors of the aviation maintenance technician (AMT) or his/her manager, but it is involved in the larger system of human factors concerns involving AMTs and managers (and others) *working together* to promote safety.

What follows here first is a review of the development of MRM through the eyes of an organizational psychologist who has observed behavioral science in the aviation maintenance scene since 1980. After that, two different and recent cases will used to illustrate "bottom-up" and "top-down" programs as separate but coincident and converging approaches to MRM. The present paper concludes with a discussion of MRM in the larger context of sociotechnical systems and organization theory in aviation.

1.2. Background

MRM is an original and creative response to an event of great significance. That response is about communication and its results in aircraft maintenance – an occupation in an industry for which communication was a largely neglected topic. The event occurred in 1988 – a 19 year old B737 aircraft, on a domestic inter-island flight in Hawaii, experienced major hull disintegration which was attributed to problems in the company's maintenance system management (NTSB, 1989). There was sudden awareness of two problems – the crisis of an aging fleet, and a crisis of communication between management and the worker in conducting safe and cost-effective maintenance operations. As MRM has evolved, and continues

to evolve in response to these problems, many airlines are discovering that solving them will require changes in management, organization, and organizational culture – changes requiring collaboration among people, changes beyond people one at a time.

Two social science studies of airline maintenance operation in the US began shortly after the 1988 accident. They were funded and subsequently published by the FAA (Drury, 1991; Taylor, 1991). Other, similar studies in airline maintenance had been conducted in Britain (Lock and Strutt, 1981) and in the Netherlands (Alders et al., 1989). The conclusions from all of these studies showed that maintenance management and group effects, such as those noted by the US National Transportation Safety Board (NTSB), could be generalized in part as a problem of poor communication practices and skills throughout the industry.

There was evidence, from some of the airlines studied, that good communication practices were in use, but that these were the exception (Taylor, 1991). Other positive results had been reported outside the US about changes in management style and structure at British Caledonian airlines (Anonymous, 1987), SAS-Scandanavian Airlines, and British Airways (Carlzon, 1987; Lima, 1995).

1.3. Maintenance and safety

Even before the 1988 accident, social scientists in government and industry were reporting that maintenance has an important impact on safety of flight. " … 39% of [widebody] aircraft accidents began with a problem in aircraft systems and maintenance, and that "pilot error" comes later in the sequence of events after something has gone wrong with the airplane itself' (from Wiegers and Rosman, 1986; as reported in Becker-Lausen et al., 1987). Quality of work results, in part, from a positive state of mind. Safety, in turn, results from quality. State of mind can be changed through effective management techniques. It follows that positive attitudes in the maintenance arena can lead to improved communication, cooperation, coordination, performance quality, and flight safety. A key to success is in management's approach to the employee as a resource, and an understanding from

and with the employee of the human factors that make a process succeed or fail.

1.4. Maintenance and the human factors national plan

In 1990 the FAA, in concert with NASA and the Department of Defense, brought together a group of human factors experts to craft the future agenda for aviation human factors research. Results from that effort included Challenges in Aviation Human Factors: The National Plan (AIAA, Washington, 1991), and The National Plan for Aviation Human Factors (FAA, Washington, 1991). Those documents, although primarily focused on human factors of the individual in aviation occupations, also reported that teamwork and sociotechnical systems, although not the prevailing culture, have advantages which are becoming recognized in the airline industry.

1.4.1. Maintenance and open communication

The National Plan document stated that the overall culture of commercial aviation still emphasized individual rather than team aspects of cockpit work. That report (and others, see Hackman, 1990) states that the same individualistic culture of the flight deck also influences airline maintenance functions. A major conclusion was that the "cockpit resource management" (or CRM) techniques (for open and assertive communication) successfully used in flight operations could be applied to aviation maintenance with good results, but that a larger system view which includes individual, team, technology, and environment (i.e., a sociotechnical systems view) is required to obtain maximum benefit from the training.

The aging aircraft fleet problem was highly visible following the 1988 accident. Concern with the condition of the fleet was largely responsible for maintenance being included in the deliberations and recommendations of The Human Factors National Plan. FAA, airlines and the manufacturers attacked the aging aircraft crisis together. The aircraft manufacturers designed modifications to extend their equipment's longevity and the FAA approved them. Airlines, in turn, quickly began hiring more AMTs to attend to the new rush of work required to bring their aging aircraft into compliance with newly mandated standards.

1.4.2. The first case of training for open communication in maintenance

In 1990 Pan American World Airways addressed its aging aircraft agenda, not merely by hiring more employees, but by beginning to train its maintenance management in assertive and open communication techniques which had been proven effective on the flight deck (Taggart, 1990). Pan Am was not an unusual case among large airlines. Its labor relations problems had been going on for many years and included strikes and protracted negotiations with the several trade unions representing the employees working in its maintenance department. Pan Am management could appreciate the importance of good human relations in completing the added work mandated by the aging aircraft crisis. Unfortunately, Pan Am could not survive the disastrous public relations repercussions of the terrorist bombing of a Pan Am 747 and the company became insolvent before the maintenance communication program could have much effect. What was learned from that exercise was that maintenance managers were very enthusiastic about the content of the training (Taggart, 1990).

1.5. The influence of flight crew training

Cockpit resource management training for flight crews was developed in the late 1970s by United Air Lines. By 1988 it had already spread to other aircarriers in the US commercial aviation industry, to various sectors of US and Canadian Military aviation, and to foreign carriers. Although the specific programs differed from one company or organization to another, cockpit resource management involved training in several team-related concepts: communication skills, self-knowledge, situation awareness, and assertiveness skills.

Cockpit resource management has been widely studied during in the years since its inception. This kind of training had been shown to work for flight crews as documented by Helmreich and his colleagues (Helmreich et al., 1986; Wiener et al., 1993). Cockpit resource management training has been extended from the cockpit to cabin crews. The

evidence has grown that team coordination among aviation "managers", and between them and subordinates, improves system effectiveness, product quality, and safety.

2. The three pillars of change

Successful organizational change can be defined as *long lasting* positive effects on end results, which are *diffused* or widespread throughout a company. To be successful, organizational change (including MRM) requires three elements to be present: (1) unequivocal top management support and vision of the purpose for the change, (2) a well conceived and relevant intervention, and (3) timely appropriate feedback, through a broad range of measurement and communication channels. These three pillars are recognized in successful cockpit resource management (ICAO, 1989). MRM has evolved in the years since 1988 and it will be instructive to examine that evolution in light of these three criteria.

3. The two roots of MRM – bottom up and top down

3.1. MRM from the bottom up

In 1992 bottom up MRM was created by the interest of the International Association of Machinists and Aerospace Workers (IAM/AW) in protecting and serving its members by helping to eliminate the sources of paperwork errors for which the members receive discipline. Union representatives approached USAirways Management and the local FAA Flight Standards District Office (FSDO) on the subject and all agreed that correction and elimination of errors was their real focus and that disciplinary action is only a means to that end. A "win–win–win" attitude among the three parties was apparent even at the initial start up and development of MRM. Everyone had something to gain – FAA and IAM both wanted fewer enforcement actions and USAirways wanted improved performance. The principals reasoned that if errors could be reduced or eliminated through discussion and collaboration, then punishment may not be neces-

sary. The three parties took guidance from the successful 1990 "Altitude Awareness" test program – a narrowly focused study to reduce altitude deviations – achieved through the collaboration among the Air Line Pilots Association (ALPA), USAir management, and the FSDO.

The three parties reasoned that AMTs want to work safely and would collaborate with others to do so, but they may lack the administrative skills, or the trust, or the communication skills, or the opportunity for collaboration with others to succeed. A research program was launched to test the effects of approaching AMTs and Foremen directly for help in reducing problems with paperwork – an important, but not usually safety related, maintenance error. The efforts in 1992–1993 with AMTs, leads and foremen at USAirways were encouraging (Taylor, 1994). The company made a special effort to measure and document the accuracy of maintenance paperwork completed by AMTs and their foremen. Those performance measures were used to evaluate the success of the program.

3.1.1. The first year of MRM

In 1992 some 100 AMTs and foremen in four line stations were brought together in 8 focus groups and were asked directly (and in confidence) what were the causes of paperwork errors and how to reduce them. These people spoke up, and where there was agreement among them, those ideas were later implemented, and paperwork errors were subsequently reduced to various degrees (depending on the specific changes made).

3.1.2. Results of the MRM focus groups

There was substantial agreement among the lists of paperwork error sources, and the lists of solutions to eliminate those sources which resulted from the focus groups (Taylor, 1994). The final list of most important paperwork error sources of all 8 initial groups (and confirmed by 10 subsequent focus groups) contained the following:

- Poor hourly-management communication about technical information.
- Confusing or conflicting maintenance system technical information.
- Poor use of post-merger "best practices" for technical communication.

- Overwhelming information requirements for through-flights
- Poor document design or clarity (e.g., Aircraft Logbook, General Maintenance Manual).
- Complex/redundant Engineering information.
- Inadequate training in paperwork.
- Antiquated information technology (e.g., computers, faxes, microfilm readers).

The final list of recommended solutions was also replicated in each of the 8 group's lists (and validated by the lists of the later 10 groups). Those recommendations included:

- Increased two-way AMT-Management communication about technical matters.
- Install newer film readers and a real time computerized logbook.
- Involve AMTs in revising the paper logbook form and to rewrite the GMM.
- Provide AMTs' review and feedback to engineers before Engineering Orders are issued.
- Reduce the number of maintenance checks (and their paperwork) on through-flights during the day.
- Provide AMT training in paperwork – including OJT and via on-shift meetings by lead or foremen.

Part of that last suggestions from these focus groups – the recommendation that AMTs needed formal training in the use of required forms and job cards – was acted on first. The company, with concurrence of the IAM and the FSDO, designed and implemented a paperwork training course for all AMTs in line maintenance. The course was delivered to all 1300 AMTs in 37 line stations. Paperwork errors diminished immediately and remained lower for nearly a year, before approaching previous levels (Taylor, 1994). This is evidence that improving purely technical content can (and does) improve safety, but it is also short lived and requires additional effort to be sustained. The paperwork training was conducted by USAir Technical Training Department personnel. It was not linked to the previous MRM efforts. Most trainees could not know and were not told that the training was the direct result of MRM focus group recommendations from the previous few months.

At the same time as the paperwork training, USAirways Quality Assurance Department an-nounced and installed a telephone hotline as another effort to open communication, following those initial MRM activities. This change was undertaken to address the first recommendation on the list. The hotline was intended for all airworthiness flight safety issues of non-emergency and non-grievance nature, and anyone in the company could use it. Mechanics were informed of the voice and FAX phone numbers and instructed in the hotline's purpose and its use. QA received and classified all calls. The calls were overwhelmingly about mechanical defects and problems in physical plant, but there were few specific paperwork problems or form design issues noted. The hotline resulted in a steady rate of about 10 calls per month for the last six months of 1993. 1994 hotline results showed a lower rate of about 4 per month. Most calls came in on the voice line. The people calling were primarily line mechanics. Overall paperwork errors did not reveal a decline in the months following the hotline's introduction, but the mere fact that mechanics and foremen were able to speak-out via an added communications channel was not expected to result in lower paperwork error rates.

3.1.3. The MRM program continued a second year

In 1993 another 50 maintenance respondents in three more line stations participated in 10 focus group interviews about problems and solutions. The results from those discussions confirmed the causes and solutions for paperwork errors presented above. Following that second round of communication management and the union agreed to implement pre-shift meetings in one line station and to have that station redesign the company's aircraft log book.

MRM experimental findings showed that improved quality of paperwork and documentation resulted from increased paperwork training, from opening communication between mechanics and foremen (in the form of crew briefings at the beginning of a shift), and direct involvement of mechanics in improving forms design. But the program resulted in improvements that lasted only for the two years that the attention of the three parties remained on it. Once union and management and FSDO attention turned elsewhere, the paperwork error rates reverted to near former levels.

3.1.4. MRM and learning from specific errors

Encouraged however, by the positive effects achieved by the intervention after the first 18 months, the three parties agreed to institute constructive, problem solving meetings about *specific* safety incidents so that the AMTs involved could help the USAirways, the union and the FAA understand contributing factors and probable causes.

Throughout the industry AMTs are often provided technical information as a task for rote memory, and not be considered in the larger context of aircraft safety and system operation (Strauch and Sandler, 1984). Technical tasks often require critical thinking and that can be enhanced through a process of open and trustful two-way communication. In many reported safety incidents technical procedures and their importance had been transmitted by technical bulletins (which in come cases had even required readers to initial a roster when they had read the document). This persistent inability for maintenance management to communicate important technical matters this way to mechanics is well illustrated by the Lockheed L-1011 three engine shut down near the Miami airport in 1982, which was caused by missing engine "O" rings (NTSB, 1984, pp. 24–26). Despite 11 previous instances of L-1011 engine shut downs due to failure to install chip detector "O" rings, together with changes in job cards to correct the problem, plus training bulletins to broadcast the problem and the changes, plus widespread management awareness of the problem and the "fixes", the mechanics involved in the NTSB reported accident were still not aware of the proper procedures. Many airlines have their own version of such communication problems, although they don't usually result in an NTSB investigation.

USAirways, the FSDO, and IAM felt that it was important to understand reasons behind specific errors not only to prevent that case from reoccurring, but also to draw conclusions for preventing errors in the larger context. The resulting USAirways maintenance problem solving meetings (which soon became known as "roundtable" meetings) were expected to be open explorations of the sources and causes of specific incidents, but were also intended to be potential avenues to appreciation of the larger context of errors as well. The roundtable meetings were open, constructive and effectively non-punitive although amnesty could not be promised (and was not always delivered). Roundtable meetings were usually limited to the erring parties and the MRM facilitators from the IAM, the FSDO and from Quality Assurance. Between 1993 and 1996 some 15 roundtables have been conducted (Kania, 1996). Following most roundtables, a short article in the USAirways Maintenance department newsletter was written by the erring parties describing the results of the meeting and lessons learned from the discussion. The specific causes covered a wide range and specific solutions were often created to address them. Many of the incidents did not involve paperwork errors and although the roundtables were not expected to improve work documentation several of them have done so (Kania, 1996).

3.1.5. MRM training developed for all maintenance personnel

The experience gained with the USAirways MRM program was valuable. During 1994–1995 the new Senior VP had implemented other changes to maintenance jobs, organizational structure, and work processes (mostly embodied in self-directed maintenance work teams). As these changes began to take hold, the company, the union, and the FSDO decided to endorse a next (and larger) step for MRM – that of changing the culture of the entire maintenance organization in achieving more open and trustful communication with a specific emphasis on improving safety. The three parties realized the advantages of bottom up focus of their original efforts and decided that culture change would require some sort of training program. Such training, they reasoned, should be jointly developed by AMTs and management with subject matter experts (SMEs) providing advice as needed. The development of this training plan was undertaken in 1996 and completed during 1997. There were several types of SMEs. They included developers of training curricula, AMTs with experience with team training techniques, as well as USAirways pilots and flight attendants with experience with cabin and cockpit resource management programs. Those SMEs, who mainly provided information in communication training content (e.g., active

listening skills, consensus decision making, assertive communication, etc.), and advice on curriculum development (e.g., making and using training videos, writing facilitator notes, preparing workshop manuals), were invited in on an "as needed and as available" basis. Little information on the technical aspects of maintenance work was sought during this development. The USAirways Maintenance Technical Training Department was not much involved.

Ongoing review of the training development was sought from USAir maintenance management, the FAA FSDO, and from social scientists external to the company. This MRM development process has resulted in a two-phase 16 hour training course in human factors knowledge, safety awareness, and communication skills, which is planned for delivery to *all* maintenance and technical operations personnel throughout the company, as well as to the Airworthiness Inspectors from the FSDO. The company will continue to evaluate the effects of the MRM intervention using attitude, behavior and performance results.

3.2. The three pillars of change applied to bottom up MRM

3.2.1. Management support

This case at USAirways provides ample evidence for this aspect of MRM. The Maintenance Senior Vice President, when approached by the IAM and FSDO with the idea of MRM as a maintenance variation of the successful "altitude awareness program", was willing to support the involvement of several line maintenance stations and provided the administrative resources required to collect paperwork performance data and mount an extensive paperwork training program. Twelve months later, his successor introduced some changes of his own, such as "self-directed teams" for maintenance and, if anything, he was even more enthusiastic about MRM and encouraged his staff to support it.

When presented the recommendations from the 1993 MRM focus groups, the Senior VP was also willing to allow implementation of the suggested ideas, at least on an experimental basis. Throughout this process the IAM local leadership and the FSDO management were also extremely supportive of the MRM initiative. This tripartite cooperation was responsible for the current participation of AMTs and management in the design of the MRM training program for all maintenance department personnel.

3.2.2. Quality of the intervention

The original initiative was clearly relevant to those AMTs and foremen that it touched. The MRM results show that observations and suggestions made by line maintenance foremen and mechanics were appropriate subjects for improvement efforts, because responding to those suggestions led to the intended reduction in errors in logbooks as well as in paperwork overall (Taylor, 1994). The various comparisons of the time-series paperwork discrepancy data before, during, and after several MRM interventions demonstrated that those interventions could be separated from the effects of a number of coincident but independent company-initiated changes in documentation procedures – e.g., using "crackdown" methods employing more stringent paperwork audits, or by "foolproofing" the signoff process by issuing individual pre-inked stamps to all AMTs and requiring their use (cf. Taylor, 1994, pp. 12–13). The form for the aircraft log was designed by mechanics in one line station over a several month period in late 1993. Logbook error data and interviews with AMT users confirmed the success of the "new" logbook (Taylor, 1994). Seven line maintenance groups at two stations interviewed during June 1994, said they liked the new logbook better than the old one. Some of the changes in the logbook included larger blocks for maintenance descriptions of work performed, more blocks containing items of relevance to mechanical quality of the aircraft, and a wider margin at the spine so that information could be written on the far left side of the form as more pages were turned over. AMTs at several line stations paid the new logbook their highest compliment by stating that it was a "maintenance-oriented log, at last." The new form excited a great deal of interest in its first ten weeks – in fact, those later interviewed had a list of suggestions to make the logbook even better. During the MRM data collection phases (May 1992 to March 1993) many mechanics and

their foremen independently appealed for greater involvement and participation in modifying and improving their forms and documents.

Since the conclusion of the initial study, the notion of foremen and mechanics throughout the company getting involved in improving the forms they use has quickly spread and is becoming an idea "in good currency." A year later several more of the company's line maintenance stations (that were not a part of the MRM data collection or experimental phases) demonstrated their interest in to participating in forms design. In April, 1994 foremen from one station offered to help redesign their "A" Check forms for several aircraft models. Mechanics and Leads at another station took matters into their own hands and independently developed a new "A" Check form for the Boeing 757 fleet of aircraft they service.

A number of AMTs from throughout the company also participated in the review and updating of their General Maintenance Manual and Administrative Manual. The new "Maintenance Policies and Procedures Manual" (MPP) is the direct result of the MRM project (USAir, 1996). Earlier focus group responses had often cited the existing manuals as a source of subsequent paperwork errors. The company's response was a participative effort, involving over 100 people, to review and rewrite their core maintenance documents. A steering committee was formed with representatives from Quality Assurance department, Technical Publications and Reliability departments, and the AMTs and their trade union (IAM). They divided the content of the two manuals into some 40 maintenance related content "sections" and those were assigned to newly formed working committees for review and rewrite. There were eventually a dozen working committees of 7–8 people each throughout the maintenance organization. Approximately 80% of committee members were from the hourly work force. After about 6 months work the rewritten sections were validated for accuracy by the appropriate (technically qualified) departments. Management reported great satisfaction with the quality of the review and rewrite work and the "user-friendliness" of the new MPP – completed largely by AMTs (Kania, 1996).

3.2.3. Feedback for reinforcement is also required for successful change

In 1993 results of the initial problem and solution gathering (see Section 3.1.2 above) were fed back to company management, the union and to the FSDO. That report back was followed by management implementing a hot line and providing paperwork training for all line maintenance employees. In the case of the design of new forms, which was undertaken after a second round of collecting problem and solutions, the quality and relevance of the intervention created its own momentum which was further diffused by the circulation of an internal report (i.e., Taylor, 1994). The news of mechanic involvement in redesigning the aircraft log book traveled fast, and enthusiasm at the shop floor was apparent. The process of continuing to collect and report outcome data during 1995 required a degree of ongoing management support that was sometimes not achieved. Without any further hard evidence that the program was effective, potential management advocates were distracted by other day-to-day issues and the program gradually lost visibility. In 1996 the Senior VP endorsed a joint labor-management safety process and announced that MRM was the vehicle to deliver it. With this renewal MRM had become a force for cultural change, not merely a passing program.

3.3. MRM from the top down

In 1991 a top-down program to improve maintenance communication began in Continental Airlines (Fotos, 1991). The idea for such a venture was the product of discussions between the Senior Vice President of Technical Operations and the Director of Continental's human factors and cockpit resource management programs. The two of them agreed that the company's success in flight deck communication could be adapted for maintenance – starting with management communication skills first. A training course was developed by Maintenance Quality Assurance and Operations managers, with help from SMEs from Continental's Maintenance Training section, trainers from the company's human factors/cockpit resource management program, and university-based training evaluation specialists.

The program, originally called "crew coordination concepts" (or CCC), was the personal agenda of the Senior VP who intended it for his departments' directors, managers, supervisors, assistant supervisors, engineers, analysts, coordinators, his other staff specialists, and inspectors – and eventually his mechanics. Following the company's model of cockpit resource management, this training was designed to improve safety and efficiency by identifying organizational norms, using assertive behaviors, understanding individual leadership, managing stress, improving problem solving/decision making, and enhancing interpersonal behavior. Technical Operations personnel conducted the training with assistance from professional training consultants. Each session began with a reference to the VP's direct interest and confidence in the program. Training included a combination of short lectures, discussions in large and small groups, individual study, and role-playing with others. That training was delivered to 2200 people, including all 1800 maintenance management and staff personnel, as well as nearly 400 inspectors and other AMTs, over a period of two and one-half years. This was accomplished with a two day training course (the location rotated among three cities) which was repeated weekly for groups of about 20 participants each.

3.3.1. MRM and CRM compared

The experience at Continental shows that MRM shares with cockpit resource management the basic issues of communication and team coordination and an interest in evaluating resulting attitudes and behaviors that relate to those issues (Fotos, 1991). But MRM, as exemplified by the Continental's "CCC" application, also differs from cockpit resource management in a variety of important ways – its target audience is more diverse than cockpit crews and includes aviation maintenance technicians (AMTs), staff support personnel and management, its goals include the reliability of technical operations processes and occupational safety as well as airworthy aircraft. A most important difference between MRM and cockpit resource management evaluations is that MRM programs have a wide variety of objective performance data available to test its outcomes. From the beginning,

MRM was intended to impact maintenance error rates – it was created to improve human reliability in measurable terms. Cockpit resource management programs are popularly assessed in terms of accidents prevented, while MRM programs can be more readily assessed in terms of performance achieved.

3.3.2. MRM performance measures

A large number of robust and appropriate indicators of maintenance performance were collected monthly for a substantial period prior to and *following* the onset of the MRM training. The performance of these indicators before and after the training were first reported in the results of a NASA-sponsored longitudinal study (Taylor and Robertson, 1995). Fourteen measures of Technical Operations performance were selected by the trainers and graded as to their suitability for assessing the training. Trainers rated several measures as best, because they combined the following: they measured safety or dependability, they reflected the efforts of people by work unit, they measured changes resulting from human behavior, and they were largely independent of the effects of other performance measures. Post-training performance improved following the onset of training. *Safety* improved. Ground damage incidents and occupational injuries had been increasing in the year prior to training, but the incidence of both measures declined after the training began. *Dependability* (on-time performance) continued to improve post-training. *Efficiency* (overtime hours paid) had been increasing, but declined post-training.

3.4. The three pillars of change applied to top-down MRM

3.4.1. Management support

Successful change requires unequivocal top management support. Continental's Senior Technical Operations Vice President created a program for all 2200 of his management and staff support personnel. The case at Continental showed that if that executive dedicates himself to that vision long enough, if he is persistent in its visible sponsorship, and if he is clear in his conviction that scientific evaluation of the program will improve its

acceptance and continued development as well as validate his vision, then results occur. His maintenance managers begin to seriously value the open, assertive communication, safe work habits, and problem-solving methods that the program espouses. Those managers reported in surveys and interviews that this program, unlike most others they experienced, really worked; and that they believed top management support for it was genuine; but they also hoped that support would be sustained though a refresher course to further develop and practice their newly acquired skills (Taylor and Robertson, 1995, pp. 49–50).

3.4.2. Quality intervention

Successful change requires a well conceived and relevant intervention. In this case the maintenance cockpit resource management program thus created was well planned and efficiently executed. It was based on the best of the lessons learned from flight-deck cockpit resource management training. The training was managed, administered and conducted by Technical Operations line managers who (not incidentally) also had good training skills. The training content and its illustrations were relevant to the work the participants do. In addition the training design required trainees to engage in active student-centered learning. As a result, they acclaimed the training as unparalleled in appropriate content, timely in the delivery of its message, and useful in its ability to be practically applied. As increasing numbers of people experienced the training and its effects became manifest, most of these participants recommended recurrent training, and many went on to endorse the wider use of the training throughout the company, including similar training for their mechanics and inspectors as well.

3.4.3. Feedback

Successful change requires timely, appropriate feedback. The Senior VP stated his aim for the program as a training program to improve human resource management using science-based tools and techniques for evaluation and diffusion. The first day of each training session opened with the purpose: To equip all Technical Operations personnel with the skill to use all resources to improve safety and efficiency. In this case, FAA and NASA funding was available to facilitate and enable novel and extensive data collection before and during the period of MRM training. Such support permitted appropriate scientific analysis of those data to test the effects of the training on maintenance effectiveness and on air worthiness and safety (Fotos, 1991). The data collection, analysis, and reporting, were done with strict confidentiality by a neutral third party, ensuring honest response to surveys and interviews. Given that those measures of MRM-relevant attitudes and behaviors were reliable and valid (cf., Taylor, 2000), the results, including feedback to the trainers as well as in reports available to all participants, provided encouragement to continue the effort. The results themselves were quite positive from the start (Stelly and Taylor, 1992; Taylor et al., 1993) and were available to all participants. Final results of training all maintenance management, supervisors and lead mechanics, staff support professionals, and maintenance inspectors traced attitudes, on the job behaviors, and performance results for two and one-half years. Those results were positive as well, although they revealed a diminished relationship between attitudes and performance a year after the training program concluded (Taylor and Robertson, 1995).

4. A systems and organizational view of aviation maintenance

Social sciences and the importance of management practices have become quite visible in aviation maintenance in the past decade. Several recent references to sociotechnical systems in aviation point to the future of MRM in the practice of human factors in maintenance (Taylor, 1991; McDonald and Johnston, 1994; Pidgeon and O'Leary, 1994; Drury, 1995). In their book Beyond Aviation Human Factors (1995), Maurino and his colleagues carefully construct the case for systems thinking and organization analysis in understanding and preventing aviation accidents. These authors emphasize the importance of recognizing the part played by complex sociotechnical systems in inducing properly qualified, healthy, and well-intentioned individuals to make damaging

mistakes. Humans, they concluded, "can never outperform the system which bounds and constrains them" (p. 83). The case illustrations throughout the book include the importance of people consulting with others and respecting others' information, because they cannot succeed alone.

A sociotechnical systems approach has been applied to understanding airline maintenance in the US. An FAA-sponsored study of maintenance bases operated by eight US companies examined the interaction of mechanics, foremen and support staff. It focused on how the technical goals were articulated and accomplished through cooperation and communication in the social system, using the methods of sociotechnical system analysis (Taylor, 1991). The study showed that maintenance personnel did not always have complete understanding of their company's policies and goals, nor did they understand their individual roles in meeting these goals. The study confirmed that effective communication is paramount for ensuring coordination and good work performance. Where communication was found not to be a high priority, there was more jobs late from maintenance, and personnel turnover was higher than average, and there was lower morale among maintenance, inspection, planning, stores, and shop personnel.

4.1. Communicating the "Why." In a purposeful system

It is important to communicate the company's purpose to mechanics, inspectors, planners and their supervisors. Not all mechanics want more communication (Forth, 1993), but many (especially younger ones) do (Taylor, 1991). There is much truth in the assertion that American industry (including airlines) has *too much* communication to employees, but it is often *not* communicating what is most important, or in the most effective way. This issue is not one of quantity of communication, but of its quality.

How do we know what is really important? Usually this can be understood in terms of the purpose of the enterprise. Why should the "why" be communicated to mechanics? There are several reasons. (1) New employees in airline maintenance no longer come from the military in the numbers they once did. In the past ex-military mechanics were accustomed to command-and-control organizations where explanations, and reasons played little part. (2) Military training, itself, has changed. Today's enlisted personnel are encouraged to seek involvement, and are provided with information as well as direction (Rogers, 1991). (3) Employees in all US industries today expect greater involvement and participation than did their predecessors. Many graduates of aircraft maintenance schools take employment outside the industry (Shepherd, 1991). Many new airline mechanics first gain experience in other industries where more open communication is encouraged. (4) The causes or logic behind things at work are no longer clear enough or apparent to mere observation. Sometimes the only way we can understand or find out, is to ask or to be told "why."

Southwest Airlines make the case for a clear purpose which guides the behavior of all of its employees (Freiberg and Freiberg, 1996). A paper by the Maintenance Control Manager of Southwest Airlines reported that their successful teamwork and interdepartmental cooperation is an outcome of their company's management culture (Day, 1994). Day also reported that their cockpit resource management training is conducted by flight operations, but other departments, including maintenance are expected to attend each session as well. This training thus becomes a vehicle for communicating across department lines, as well as providing a set of useful communication tools and skills.

4.2. Maintenance errors and management

Evidence continues to accumulate that the management and organizational effects in aviation maintenance are among the latent causes of errors and mistakes. This is due in part to the difficulty of communicating across many layer and levels of organizational hierarchy and separate departments (i.e., most people are too busy and distracted to hear the message from another department of from several levels down the chain of command). It is also the result of accumulated distrust and fear bred from a punishment-centered management

style (Cornell, 1968), combined with many years of active and passive labor-management conflict. By correcting these structural and policy obstacles this larger systems context also provide some of the greatest levers for improving quality and safety (Drury and Lock, 1995; Marx and Graeber, 1994).

The FAA-sponsored Maintenance Human Factors Handbook (1995) has several sections dealing with topics relevant to MRM – with maintenance teamwork, and sociotechnical systems. The FAA has also supported the development of a computer-based training technology for teambuilding (Gramopadhye et al., 1996). Sociotechnical systems thinking has also featured in recent reviews of aviation accidents (Pidgeon and O'Leary, 1994) and studies of European ground service and ramp personnel (McDonald and Fuller, 1994). A current theme in aviation maintenance is that good communication is required as a foundation for organizational changes to succeed. It is becoming recognized that this is tantamount to a cultural change – a series of beliefs: (1) that systems are larger than individuals, but that people collaborating can succeed, (2) that individuals benefit from communication skill training, (3) that top management and union support are essential for a strong culture, and (4) that aviation safety can improve only if it is a central part of the organization's culture.

4.3. Current practices for cultural change in maintenance

Practical applications of systems thinking and culture change usually take the form of changes in management behavior, changes in jobs and organization structure, changes in strategy and policy, and/or changes in values. Evidence from aviation maintenance, collected during the 1990s, confirms this (Rogers, 1991; Liddell, 1993; Day, 1994; Scoble, 1994). Virtually all of this practice involved communication and collaboration among people.

At the eighth FAA Meeting on Human Factors in Aircraft Maintenance and Inspection (November, 1993) three invited speakers described the positive effects of new task allocation and communication among maintenance crew members in their three airlines. A change in organization and

job design of inspectors at United Airlines was reported, in which inspectors remained accessible during the entire period of heavy checks, stayed in closer communication with mechanics during repairs, and "bought back" their own initial non-routine defects (Scoble, 1994). These changes were reported to result in lower total check costs, fewer air turnbacks, and higher subsequent quality. A strong and clear organization culture created and sustained by Southwest Airlines" CEO, Herb Kelleher, was reported to result in improved communication between Maintenance and other departments (Day, 1994). At TWA, a program for communication among the IAM, AMTs and Maintenance management was said to have resulted in improved quality control (Liddell, 1993).

4.4. Improving maintenance reliability through open communication

4.4.1. Combination of planning and learning

Qantas, the Australian airline, has an unblemished accident record – the company's safety policy emphasizes planning activities to avoid accidents and using an organized approach. But for many safety experts strategic planning is not enough. Management planners always benefit from new information from the field, because complexities of the operational world require that the system be constantly vigilant to new events, new behaviors, new information that can be important safety precursors. A number of programs and techniques have recently appeared to help maintenance systems uncover that new information. The bottom-up MRM approach at USAirways, described above, is one such method – others include "MEDA", "MESH", and "ASRS for Maintenance" as described below.

Aviation Safety Reporting System (ASRS) is a database maintained by NASA, in which erring parties can voluntarily describe their actions and for which they are guaranteed protection against punishment or discipline, except in the case of illegal acts. ASRS has been widely used by aircraft pilots for a number of years, but specific arrangements for AMTs have only recently been approved.

Maintenance Error Detection Analysis (MEDA), introduced by Boeing is a formal paper- and

computer-based HF database on minor quality lapses known at the local level. Using a "Contributing Factors Checklist", MEDA is intended to increase visibility of these lapses and the use of common language across participating airlines can reveal systemic deficiencies. MEDA is a large, complicated program and it takes time to coordinate – and in practice mechanics seem to require "amnesty" to reveal these lapses – trust and open communication are important.

This AMMS commercial produced is no longer offered or available from any source.

With the Maintenance Engineers Safety and Health (MESH) system, British Airways Mechanics ("Engineers") describe ongoing problems and lapses on a weekly basis on a windows-based PC. The resulting database is designed to help gauge the health of Maintenance activity or facility and trigger local warning indicators leading to greater situation awareness.

4.4.2. Evolving MRM

Most major US airlines have implemented MEDA, AMMS, or ASRS for Maintenance on at least a trial basis. Many of them are finding that trust in open communication still requires attention which is leading to an increased interest in communication training for maintenance. This combination of systems for error identification and improved communication require literally a cultural change, which can be seen as the continued evolution of MRM. In 1994 a human performance in maintenance (HPIM) training program was offered to the industry by Transport Canada (Dupont, 1996). HPIM was developed in response to the 1989 F28 accident in Dryden, Ontario, and it was inspired, in part. by the Continental MRM training approach. Since 1995 a sizable number of such courses have been placed on the market by commercial training consultants. Recent warnings about the difficulty of implementing a packaged training program for maintenance highlight the importance of AMT involvement in the success of such programs (Lofaro, 1996).

We can speculate that flawed technical information AMTs use might account for most safety related errors, and that recent improvements in that technical information might be more important for

better safety results than improved attitudes and open communication. However, true that argument may become in the future, the period (1991–1994) and the people described in the present paper had much room for improvement in the mode and motivation of AMTs to use the technical information available to them. It is a reasonable assumption that the cases reported here are representative of the industry as a whole during the current period.

As previously noted "voluntary disclosure" programs such as ASRS and MEDA might be the vehicle for the improved technical information for safety improvements in the future. All of these programs, however, require a degree of trust between AMTs and their management that quite simply did not exist in 1991–1994 – and is still far from sufficient. MRM is intended by the companies reported here to improve that trust by training and by experience with new behaviors and attitudes. MRM is about trust and open communication in order to improve technical communication and the content of technical information.

Neither the USAirways or Continental cases described in this paper benefited from much new or improved technical information during the time of the study. Although in USAirways the new technical manuals (described in Section 3.2.2) – which were created by AMTs at the end of the study period – did include improved technical information, it was too late to affect the safety results referred to here. Also ASRS and MEDA were only introduced in USAirways and Continental several years after these studies were completed. It is extremely important to assess the impact of such voluntary disclosure programs in future studies.

5. Conclusions

MRM has evolved from AMT participation in safety improvements, together with training to enhance communication skills, and the understanding that the purpose of the larger enterprise is important and must be understood by AMTs and management alike. The evidence, accumulating since 1988, seems clear that the separate pieces of employee involvement, open communication, and commitment to purpose – in concert with excellent

technical content of information in the maintenance system – all contribute to increased maintenance safety, efficiency, and performance. MRM is none of these pieces separately, but it is all of them in the context of the organization, or sociotechnical system.

References

Anonymous, 1987. Industrial relations management and the maintenance engineer. Proceedings of the British Air Transport Industry Training Association, pp. 101–108.

AIAA, 1991. Challenges in Aviation Human Factors: The National Plan. American Institute of Aeronautics and Astronautics, Washington.

Alders, B., Bilderbeek, R., Buitelaar, W., 1989. Study into the changing duties of aircraft mechanics against the background of technological developments in aircraft maintenance in KLM. STB-TNO Centre for Technology and Policy Studies, Apeldoorn, The Netherlands.

Becker-Lausen, E, Norman, S., Pariante, G., 1987. Human Error in Aviation: Information Sources, Research Obstacles and Potential. NASA Ames Research Center, Moffett Field CA.

Bradley, P., 1995. Maintenance resource management. Business & Commercial Aviation 77 (3), 106–112.

Carlzon, J., 1987. Moments of Truth. Harper & Row, New York.

Cornell, C.E., 1968. Minimizing human errors. Space/Aeronautics, 72–81.

Day, S., 1994. Workforce procedures and maintenance productivity at Southwest Airlines. Proceedings of the eighth Conference on Human Factors Issues in Aircraft Maintenance and Inspection. Office of Aviation Medicine, FAA, Washington, DC, pp. 159–166.

Drury, C., 1991. The maintenance technician in inspection. In: Shepherd, W., Johnson, W., Drury, C., Taylor, J., Berninger, D. (Eds.), Human Factors in Aviation Maintenance Phase 1: Progress Report. Federal Aviation Administration, Office of Aviation Medicine, Washington, DC.

Drury, C.G., 1995. Work design. In: FAA, The Human Factors Guide for Aviation Maintenance. DOT/FAA/AM-, Office of Aviation Medicine, Washington, DC (Chapter 6).

Drury, C.G., Lock, M.W.B., 1995. Reliability in Aircraft Inspection: UK and USA Perspectives. FAA/CAA Joint Paper.

Dupont, G., 1996. First test flight of HPIM Part 2 Workshop. Ground Effects. 1(2).

FAA (Federal Aviation Administration), 1991. The Aviation Human Factors: National Plan (Draft). Washington, DC.

Forth, K.D., 1993. Squeaky wheel gets grease – and training. Aviation Equipment Maintenance, August, p. 56.

Fotos, C.P., 1991. Continental applies CRM concepts to technical, maintenance corps, and Training stresses teamwork, self-assessment techniques. Aviation Week and Space Technology, August 26th, pp. 32–35.

Freiberg, K., Freiberg, J., 1996. Nuts: Southwest Airlines' Crazy Recipe for Business and Personal Success. Bard Press, Austin.

Gramopadhye, A.K., Kraus, D.C., Rao, P., Jebaraj, D., 1996. Application of advanced technology to team training. Proceedings of the Human Factors & Ergonomics Society 40th Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 1072–1076.

Hackman, J.R., 1990. Groups That Work. Jossey-Bass, San Francisco.

Helmreich, R.L., Foushee, H.C., Benson, R., Russini, R., 1986. Cockpit management attitudes: exploring the attitude-performance linkage. Aviation, Space and Environmental Medicine 57, 1198–1200.

ICAO, 1989. Human Factors Digest #2: Flight Crew Training. International Civil Aviation Organization (ICAO), Montreal.

Kania, J. 1996. Panel presentation on airline maintenance human factors. Proceedings of the 10th FAA Meeting on Human Factors in Aircraft Maintenance and Inspection. DOT/FAA/AM, Office of Aviation Medicine, Washington, DC.

Liddell, F., 1993. Quality Assurance at TWA Through IAM/FAA Maintenance Safety Committee. Proceedings of the Eighth FAA Meeting on Human Factors in Aircraft Maintenance and Inspection. DOT/FAA/AM-, Office of Aviation Medicine, Washington, DC, pp. 167–178.

Lima, E.P., 1995. Pioneering in People. Air Transport World, April.

Lock, Strutt, 1981. Reliability of in-service inspection of transport aircraft structures (CAA Paper 5013). Civil Aviation Authority, London.

Lofaro, 1996. Maintenance resource management. Aviation Maintenance Technology, September, p. 90.

McDonald, N., Johnston, N., 1994. Applied psychology and aviation: issues of theory and practice. In Johnston, N., McDonald, N., Fuller, R. (Eds.), Aviation Psychology in Practice. Avebury, Aldershot, Hants.

McDonald, N., Fuller, R., 1994. The management of safety on the airport ramp. In: Johnston, N., McDonald, N., Fuller, R. (Eds.), Aviation Psychology in Practice. Avebury, Aldershot, Hants.

Marx, D.A. and Graeber, R.C., 1994. Human error in aircraft maintenance. In Johnston, N; McDonald, N. and Fuller, R. (Eds.) Aviation Psychology in Practice, Avebury, Aldershot, Hants.

NTSB (National Transportation Safety Board), 1984. Aircraft Accident Report NTSB/AAR-84/04. Washington, DC.

NTSB (National Transportation Safety Board), 1989. Aircraft Accident Report NTSB/AAR-89/03. Washington, DC.

Pidgeon, O'Leary, 1994. Organizational safety culture: implications for aviation practice. In: Johnston, N., McDonald, N., Fuller, R. (Eds.), Aviation Psychology in Practice. Avebury, Aldershot, Hants.

Rogers, A.G., 1991. Organizational factors in the enhancement of aviation maintenance. Proceedings of the Eighth FAA Meeting on Human Factors in Aircraft Maintenance and Inspection. DOT/FAA/AM-, Office of Aviation Medicine, Washington, DC, pp. 43–63.

Scoble, R., 1994. Recent changes in aircraft maintenance worker relationships. Proceedings of the Eighth FAA Meeting on Human Factors in Aircraft Maintenance and Inspection. DOT/FAA/AM-, Office of Aviation Medicine, Washington, DC, pp. 45–59.

Shepherd, W.B., 1991. Demographics of aviation maintenance technicians for the '90s and beyond. In: Challenges in Aviation Human Factors: The National Plan. American Institute of Aeronautics and Astronautics, Washington.

Strauch, B., Sandler, C.E., 1984. Human factors considerations in aviation maintenance. Proceedings of the 28th Annual Meeting of the Human Factors Society, pp. 913–916.

Stelly Jr., J., Taylor, J., 1992. Crew coordination concepts for maintenance teams. Proceedings of the Seventh International Symposium on Human Factors in Aircraft Maintenance and Inspection – Science, Technology and Management: A Program Review. Federal Aviation Administration, Washington, DC.

Taggart, W., 1990. Introducing CRM into maintenance training. Proceedings of the Third International Symposium on Human Factors in Aircraft Maintenance and Inspection. Federal Aviation Administration, Washington, DC.

Taylor, J.C., 1991. Maintenance organization. In: Shepherd, W., Johnson, W., Drury, C., Taylor, J., Berninger, D. (Eds.), Human Factors in Aviation Maintenance Phase 1: Progress Report. Federal Aviation Administration, Office of Aviation Medicine, Washington, DC.

Taylor, J.C., 1994. Maintenance Resource Management (MRM) in Commercial Aviation: Reducing Errors in Aircraft Maintenance Documentation (Final Report of 1993–1994 Project Work). University of Southern California, Institute for Safety and Systems Management, December 1994. Available electionically at 'hfskyway.com".

Taylor, J.C., 2000. Reliability and validity of the Maintenance Resources Management/Technical Operations Questionnaire. International Journal of Industrial Ergonomics 26, 217–230.

Taylor, J.C., Robertson, M.M., Peck, R., Stelly, J.W., 1993. Validating the impact of maintenance CRM training. Proceedings of the Seventh International Symposium on Aviation Psychology. The Ohio State University, Columbus, Ohio, pp. 538–542

Taylor, J.C., Robertson, M.M., 1995. The Effects of Crew Resource Management (CRM) Training in Airline Maintenance: Results Following Three Years Experience. National Aeronautics and Space Administration, Washington, DC.

USAir, 1996. New Maintenance Policies and Procedures Manual (MPP). USAir Maintenance Training, No.2 (April), USAir Maintenance Training Department, Pittsburgh.

Wiegers, Rosman, 1986. The MacDonnell-Douglas Safety Information System (SIS). Proceedings of the International Air Safety Seminar. Flight Safety Foundation.

Wiener, E.L., Kanki, B.G., Helmreich, R.L., 1993. Cockpit Resource Management. Academic Press, San Diego, CA.